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ABSTRACT

Perspectives on a psychological approach to learning are offered in this paper. Specific emphasis is directed to the assumption that children possess "minitheories." Minitheories are defined as attempts to make sense of particular kinds of experiences and are explained and delimited by the domain of experience to which they currently apply. This paper reviews: (1) basic assumptions and accompanying guide questions on this approach to science learning; (2) specifics about the dimensions and impacts of children's minitheories; (3) ideas on the learning process; (4) descriptions, examples, and comparisons of gut ("experiential") science, lay science, and school science; (5) perspectives on the potential overlaps, conflicts, and resistances related to mini-theories; and (6) ideas on the aims of science teaching. A reference list is also provided. (ML)

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MINITHEORIES: A MODULAR APPROACH TO LEARNING APPLIED TO SCIENCE

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1. INTRODUCTION

If the school science teacher is the Sower, how are we best to conceptualise the state of the soil onto which his seed falls? Certainly some of his pupils will be Fertile Ground, hearing the work, understanding it, retaining and developing it. But what happens when the enterprise runs into difficulties? Are the pupils, as many currently assert (e.g. Shayer, 1980), Stony Ground - intellectually unable to support the growth of the difficult new ideas the teacher is broadcasting? Or is the problem not that the soil is barren, but that it is already occupied by a tangle of uncultivated thorns and briars that choke the new ideas, thereby resisting being surplanted? Of course these two causes of failure to learn are not incompatible. It is likely that some bits of knowledge are too difficult for the learner, and others are resisted because they conflict with pre-existing beliefs. However, up until recently, it has been generally assumed that the problem is the absence of some necessary knowledge or ability. Clearly if we are to prescribe appropriate treatment, then the diagnosis has to be right; it is now beyond dispute that the Stony Ground assumption is not the whole, or even the main part of the story. It is the purpose of this chapter to outline the alternative.

2. BACKGROUND

This alternative approach to the science teacher's and the science student's difficulties rests on a number of basic assumptions. Some of them are supported by research, others are matters of intuition or conviction.

(i) Children know a lot of science. In the last ten years a considerable amount of research has shown that children do not enter science lessons devoid of ideas and intuitions about science topics. On the contrary they usually do have quite clear expectations and explanations that may or may not agree with conventional scientific wisdom. Topics investigated so far include energy (Solomon, 1982), pressure (Engel, 1981), potential (Archenhold, 1975), heat (Erickson, 1979; Tiberghien, 1980), force (Viennot, 1979), the Earth (Nussbaum and Novak, 1976), light (Guesne, 1978), dynamics (Saltiel, 1981), and various ideas in chemistry (Johnstone, MacDonald and Webb, 1977). Reviews have been produced by Driver (1981), Hewson (1981), Watts (1982), West and Fensham (1974) and others.

(ii) Children are scientists. Not only do they have ideas about how the world works; children have theories that underline and produce those ideas. Their understanding is not acquired parrot-fashion, but arises from some more-or-less consistent framework that has been built up over a long period out of their experience. Indeed I would subscribe to Kelly's (1955) view that all their (and our) actions and intuitions are generated by such a personal theory.

(iii) Children are inconsistent scientists. The next assumption is that children (like all of us) possess not one grand coherent thoery but a whole host of "mini-theories", some of which are inconsistent with each other. When circumstances change, children are quite likely to switch points of view, and one will find them arguing or acting in ways that are quite incompatible with their previous position. Though this troubles us, it does not seem to trouble them nearly so much.

(iv) Mini-theories have a focus and a range of convenience. Each mini-theory starts out as the attempt to make sense of a particular kind of experience (heat, relative motion, gravity, inter-personal relations...). This original domain of experience is what Kelly (1955) called the "focus of convenience" of the theory. Subsequently it gets expanded to include other kinds of situation where it has been successfully applied. This developed domain is called the "range of convenience" of the mini-theory.

(v) All knowledge and skill possesses a range of convenience. This natural extension of the previous assumption turns out to be quite radical. In education, and until recently in psychology, it has been universally assumed that people can possess "knowledge", "concepts", "skills", "abilities", "capacities" or whatever, in a way that is or can be context free. I (Claxton, 1980), and others (most notably Allport, 1980) have argued conversely that all cognitive mechanisms and representations are context-specific. The force of this view will emerge in what follows, though there is not room here to justify it.

(vi) When existing theories are inadequate, we learn. The most powerful stimulus for the development of a theory is its failure. Children possess a number of learnt strategies for responding to the demonstrated inadequacy or inconsistency of a mini-theory.

(vii) We vary in our personal commitment to our mini-theories. Some of our points of view we can give up, or experiment with, easily. Others, which we hold particularly dear, may be very resistant to change. Thus the level of our commitment to a mini-theory may determine quite crucially the way we respond to its disconfirmation.

These presuppositions define a general psychological approach to learning in general, to science learning in particular, and to the resistance to learning from science teaching in even more particular. We can now formulate the following questions:

a) How can we best conceptualise children's knowledge of the world?

b) How can we conceptualise the occasions on which that knowledge is likely to change?

c) How can we conceptualise the ways in which it changes?

d) How can we conceptualise the differences between school science and children's pre-existing scientific notions?

e) How can we conceptualise the interaction between these different kinds of knowledge?

f) Under what circumstances is it more or less difficult for a pre-existing theory to be given up in favour of a formal scientific theory?

g) What teaching strategies, curriculum developments and research avenues are suggested by this analysis?

The rest of this chapter pursues answers to these questions.

3. THE THEORY OF THEORIES

Children as well as adults are scientists in the sense of being both theorists and experimenters. All their dealings with the physical and biological worlds (which are the domains on which the present discussion focusses) are mediated by a theory that has arisen partly from direct experience and partly from informal tuition. All their actions, intuitions and explanations

arise out of such theories and the consequences of action form the experimental data on which the theories feed and grow. Each "mini-theory" is born out of the need to make sense of, and act effectively within, a new type of situation, (the "focus of convenience" of the theory). Once a successful way of constructing is found, then the same framework or point of view can be applied to other, novel but similar, events. If the theory copes successfully with such an event, then the specification of its domain of experience is altered to include it. Thus a mini-theory gradually, through learning, broadens and refines its "range of convenience", and the boundaries beyond which it fails to predict and explain accurately are discovered. Each mini-theory is defined and delimited by the domain of experience to which it currently applied, and by which it is activated. A successfully "located" theory is one which is triggered by just that set of environmental cues or features to which its predictions apply accurately. An immature or imperfectly located theory is sometimes triggered by situations to which it is not in fact applicable, and sometimes dormant in situations to which it is potentially applicable. Much of a child's early learning is of this sort: it broadens and refines the specification of when to apply a particular set of predictions (Donaldson, 1978). We might imagine the developing set of mini-theories as being like a large number of amoebae trying to find their "right place" on a flat board that represents our experience (see Figure 1).

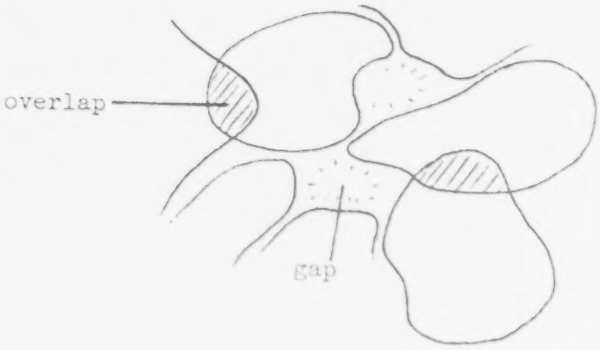


Figure 1.

The only way they can find out where the "right" place is is by sticking out an arm into a new area and seeing whether it gets smacked or not. Notice from figure 1 that as well as the issue of the appropriateness of the domain to which a mini-theory applies, there are some domains of experience that are covered at the moment by no theory ("gaps") and there are some that are covered by more than one theory ("overlaps"). We shall discuss gaps in the next section, and overlaps later. We shall see that when a child starts to learn school science the issues of overlaps, what to do about them and how they are resolved becomes a crucial one.

So far we have said little about the contents of each mini-theory. What does it consist of? Once it is triggered, what happens? What does it make available? For present purposes we may consider a theory to consist of, in addition to a specification of the Situations to which it applies, a set of Predictions, Actions, Descriptions and Explanations, which give us the appropriately functional acronym of a SPADE. A theory tells us what is likely to happen next, given what is happening now. It tells us what to do, on the basis of these predictions, in order to bring about one state of affairs rather than another. It tells us, in other words, how to divert the flow of events in our own interests. The "SPA" bit of the SPADE often operates, and operates best, in an unconscious, unarticulated, spontaneous and intuitive way. It can work without being "understood". But after the child has learnt language, he acquires the ability to talk about a domain, what happens within it, and how its different components are related. He develops a set of descriptions and explanations that are, by definition, capable of being brought into consciousness and articulated in words or other symbols.

The domains of experience to which a mini-theory may apply vary from relatively fixed, invariant scenarios (what Minsky [1977] has called "frames") through to particular triggers that may occur in a whole range of otherwise diverse contexts. At the former end we have the mini-theories that apply to bath-time, birthday parties or Mr. Clark's lessons. Once the present situation is assigned to one such specification, then a learnt "programme" of expectations, habits and ways of talking and thinking is "plugged in". Each of these examples applies to a small range of situations because their specifications are relatively full and detailed. (Note that specificity is different from frequency. Bath-times are much more common than birthday parties.) In contrast, the child develops more general-purpose mini-theories about objects and events that crop up in a variety of guises - water, balls, fire, other children, and so on.

What Kelly calls "constructs" are particular types of what I am calling mini-theories. In the present terms the construct kind, say, represents the Situation or head-code for a learnt set of predictions, actions, descriptions and explanations that are to be deployed, or are available to be deployed, when one construes oneself to be in the presence of a kind person. The description of mini-theories is both more general than Kelly's "constructs" and more appropriate to our present concerns. But much of what Kelly has to say can be applied to mini-theories. Just as constructs can be connected by different types of relationship so for example one mini-theory may be nested within another.

For some purposes we can treat mini-theories, like amoebae, as being relatively well-bounded. It is probably more accurate though to think of them as having fuzzy boundaries, so that their range of convenience, or the sphere of influence, does not stop dead, but diminishes more gradually. Joan Solomon has suggested that mini-theories may be seen as street lights "illuminating" a certain patch of ground (or "casting light on" certain phenomena), which fade off into shadow at the edges, or begin to merge ("overlap") with the next light. Half way between two sources of illumination we find that predictions, like shadows, are both less distinct, and multiple. As one moves towards one of them, so one set of expectations sharpens up while the other fades away.

How stable are these mini-theories? Should one see them as slithering about at a high rate of knots, or as being firmly sunk into the ground and requiring much effort to shift? The answer is "it depends". Theories exist to cope with circumstances, and if circumstances are shifting fast, so will the theories. Childrens' theories on the whole will be changing faster than adults', and young childrens' very fast indeed, - though the first fortnight in a very different culture will produce some rapid learning in anyone. Basically we might say that a theory lasts as long as it is successful.

There is a kind of pseudo-change that we might mention that looks as if theories are on the move when they are not. When one is operating in the "twilight zone" between two mini-theories, one may flip backwards and forwards between the two different points of view, arguing vociferously for A one minute, and acting on the basis of B the next. The successive espousing of wildly different positions (said to be typical of the adolescent) is thus often symptomatic of the learning process and not of the relocation of mini-theories as such.

4. LEARNING

The SPADE, the amoeba and the street light are handy images for conceptualising what we know. We need now to consider the circumstances and the ways in which

our knowledge changes. What happens when we learn? When do we learn? And how does learning take place?

What happens when we learn is that some part of a SPADE changes. Next time we may be inclined to expect something different (P), behave differently (A), or describe and account for what is going on in a different way (D and E). But in addition to or instead of the content of a mini-theory changing, the specification of the situations to which it is applicable (S) may also change. What is in the amoeba stays the same, but it shifts its location. Traditionally psychologists have focussed exclusively on changes in what people say and do. Now the compelling work of Cole and Scribner (1974), Donaldson (1978) Allport (1980) and others have revived our appreciation that of equal significance is when they say and do it. Probably the majority of a young person's learning is to do with choosing the right tool for the right job - when to use a conceptual screwdriver and when to use a hammer. Conversely most of their botches are caused not by ignorance but by the application of an inappropriate theory.

There is a deep problem here that it is important for educators to overcome. Because we can talk about "concepts" and "skills" it is easy to think that they exist in the same way as books and tool kits exist - as independent bits of knowledge that one can "acquire" exactly as one acquires a newspaper or a paint-brush. What we forget is that in both cases possession is a necessary but not a sufficient condition for effective use. I have also to acquire knowledge about how to wield my new paint brush, and what sort of job it is suited for. Just so, know-how and know-that are useless without know-when, and it is for this reason that mini-theories always combine both sorts of information. Teachers pay a lot of attention to communicating facts, concepts and techniques, and almost none to the explicit transmission of those vital senses of occasion and purpose. We shall see how important this omission is later.

When does learning happen? The most unobtrusive kind of learning occurs when a mini-theory produces a successful prediction, action etc. The only change we need make is an increased confidence in the specifications of S,P,A,D and E, and in the fact that they belong together. More interesting is when the theory fails - and failure may be of three sorts, over-extension, under-extension and conflict. Over-extension is often what we are aware of first, we apply a mini-theory to a new situation, and it lets us down. We assume that this use of the word "force" is the same as previous uses, but find that the everyday connotations are out of place in the physics lab. The amoeba is where it oughtn't to be. Under-extension may follow over-extension or may occur on its own: it occurs when we find a gap or a hole in our theory so that experiences occur which we do not know how to deal with. The amoeba isn't where it ought to be. Finally conflict occurs when we suffer not from a lack of suggestions but an excess of them. Two or more mini-theories are triggered by the same event, and they give rise to incompatible predictions and interpretations. Either this is a party, in which case I should relax and have fun. Or its a group interview, in which case I should be on my guard and my best behaviour. A number of amoebae are vying for the same spot.

The next question is: what follows the perception of a learning opportunity? What strategies do we possess for dealing with these uncertain times? To put it another way, what mini-theories do we possess whose Situations are "failure" in one form or another of the theoretical system? I have written about this at length elsewhere (Claxton, 1984) , but briefly there are two kinds of strategy - approach and avoidance, or learn and defend. If we choose to learn, then the job is to discover or develop a way of looking at the current situation that is appropriate and effective. First we try to discover an existing mini-theory that will work, and if that fails, we may have to try and put together a new one. Some of these strategies are obvious. The most likely response to over-extension is withdrawal. This then leaves us with a gap

(under-extension), so we may then tentatively advance another mini-theory into the same area to see if it works any better. Alternatively we may modify constituents of the original theory to see if we can get it right.

Of prime interest here is what we do in the face of conflicting predictions, generated by an overlap of two or more theories. If we want to learn, then clearly we have to investigate, experiment and eventually resolve the conflict, either by integrating the two theories or by confining each to its appropriate territory. However we may choose not to learn but to defend: we shall investigate what this involves in Section 9. The issue of how we deal with overlaps is the crucial one here, because, as we have seen, they are the science teacher's biggest problem. What prevents new theories "going in" is not that they fall in the middle of huge gaps in children's knowledge, nor that the children lack appropriate learning strategies. It is that there are lots of little amoebae there already that the new theories conflict with. And, as we shall see, students typically react to this by confining school science to its own separate domain, and/or by defending against acknowledging the conflict, in which case resolution never occurs.

If overlapping theories are to be integrated, then one of three outcomes is required: either one theory engulfs the other, or an abstraction is created or the boundary between the two is dissolved so that they merge into one big mini-theory. Engulfing occurs when one mini-theory turns out to be a special case of a more general theory that has developed independly. Research science often registers progress in terms of engulfment, as when Newtonian mechanics was engulfed by quantum mechanics. Abstraction occurs when a number of originally separate mini-theories are found to contain a common sub-theory. A child may have developed separate mini-theories to deal with drinks, boats, bath-time and the local pond, and then come to see that there is a reliable and predictable trans-situational component of all of them called water (see figure 2).

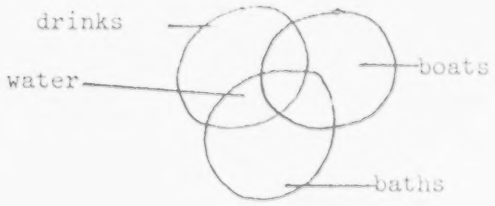


Figure 2

Merging occurs when we realise that we have developed two complementary ways of dealing with what turns out to be the same type of situation.

To illustrate the spirit of this analysis, imagine a child confronted with the hypothetical question "what will happen if we drop this weight into this measuring cylinder of water"? Suppose the child does not yet possess a trans-situational mini-theory about water, but he does possess mini-theories about drinks, baths, boats and beds, all of which surround the gap in which the target phenomenon is located (figure 3). He can advance any one of these theories into the gap in order to generate a prediction, because each of them has something to say about the situation of lowering a solid object onto or into a "squishy" medium. If he chooses drinks, he may say that the water level will remain unchanged - because when he puts a spoonful of sugar into a cup of tea, no change in the overall volume is noticed. If he advances boats, he will get the same answer, because neither the sea nor the local pond visibly rises or falls when a real or a toy boat is launched. If he uses the beds mini-theory, however, he may predict that the water level will go down - because his bed

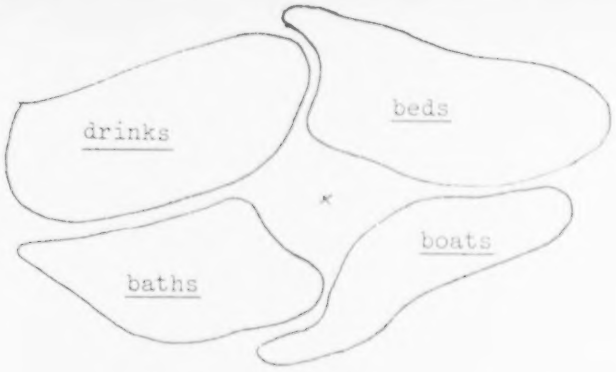


Figure 3

goes down when he lies on it. And, finally, if he chooses to base his prediction on baths, then he will say that the level will go up, because that is what happens when he gets into the bath. Associated with each of these predictions one may be able to elicit an explanation. The drinks theory supports its prediction by generating "the weight will just disappear, like the sugar". Boats predicts no change because "the weight will just sit on the water like a ship". Beds gives us "the water level goes down because the weight squashes it". And baths generates the explanation that "the weight will push the water out of its way, so it will have to go upwards". Note that only baths generates the correct prediction, and also something like the formal science explanation. Note that every other answer is a perfectly rational deduction from an inappropriately applied theory. And note too that there is no way that the child can know which will turn out to be "correct" ahead of time. He has no alternative but to gamble on the basis of his existing knowledge.

Which theory a child will choose to bet on may depend crucially on apparently small details of the way the task is presented. To an adult, sinking a toy battleship in a washing-up bowl, drowning a toy soldier in the bath, dropping a marble into a cup of tea, and slipping a cylinder of copper into a tall glass tube can all be seen, in some respects, as examples of the same thing. But to a child they are not. He has yet to learn what there can be in common between these events. He has to discover that the phenomenon of displacement is "conserved" across these situations. Until he has developed a mini-theory about fluids and their displacement by solid bodies, each one of the situations may call a different mini-theory. We might speculate, along the same lines, that a different mini-theory might be activated depending on whether the child is asked to give a verbal prediction plus explanation, or whether he is shown the weight and the cylinder and told "now close your eyes and imagine the weight being lowered slowly into the water. Watch what happens to the water level.. OK... what did you see?" There are some interesting experiments that arise from this speculation. It is at least plausible because, as we shall see, the descriptions and explanations that are offered for a phenomenon often arise out of a different but overlapping mini-theory from the one that generates intuitions and spontaneous reactions. Gut science, lay science and school science, to which we now turn, are frequently to be found talking at cross-purposes in this way.

5. GUT SCIENCE

In this and the following two sections, we shall look briefly at the special characteristics of those clusters of mini-theories that we shall call gut science, lay science and school science. These are not tightly defined, nor clearly separable from each other, but their forms, functions, and focusses have different emphases. Table 1 illustrates the features that are discussed in these sections.

The domain of gut science is the child's world of immediate experience. It derives from his first-hand explorations of and interactions with physical and biological phenomena. Children learn a gut physics by dropping bottles, touching hot plates, pushing toy cars about and falling over. They learn a gut chemistry through tasting and smelling, seeing the toast burnt and by dropping a sugar cube into Coca-Cola to see what happens. They learn a gut zoology by pulling the cat's ears, a gut botany by helping Daddy in the garden, a (literally) gut physiology by eating too much ice cream, and so on. Gut science rests in a child's bones, and manifests itself primarily in his spontaneous reactions, intuitive judgements, and everyday perception. Although later on gut science will be influenced and modified by what he is taught, both at home (lay science) and at school (school science), its foundations are laid by his active efforts to comprehend the physical world in his first year of life. The sensori-motor child is a lively and intelligent scientist, albeit an intuitive one. He formulates hypotheses, emits behavioural experiments, notes the consequences and modifies the content and scope of a theory accordingly. The criterion against which each theory is tested is: Does it work? Is it useful? Later on he will have to pay attention, at least in expressing descriptions and explanations, to other, social criteria of convention and acceptability. (He can say "Naughty Bobby hit me", but not "Naughty Hottie burnt me".)

Much of gut science is incoherent: that is, it consists of many local theories, each with its own domain, with very little concern for integration and consistency between domains. And much too is inarticulate. It is not available to consciousness, and incapable of being expressed. "Real" academic sciences such as physiology, psychology and linguistics are the endeavours to derive descriptions and explanations for aspects of our inarticulate gut science. The descriptions and explanations of gut science are tied closely to a person's direct experience. Authentic gut explanations often boil down to "because I know it" - not intellectually but experientially.

6. LAY SCIENCE

Lay science has its origin in the form and content of the language that a child grows up to speak, and, in the industrialised world, in the accounts and images of experience that are conveyed to him by the media. If his community speaks one of the Indo-European languages, for example, his whole way of talking is constrained to be "thing"-based, because the language is noun-based, and to presuppose the notions of cause and effect which are embedded in the subject-predicate nature of such languages. If, on the other hand, he is Chinese, or a Navaho Indian, these linguistic constraints will be replaced by others that are "event"-based and synchronous. Whether his language presupposes substance and stasis, which are the bases of a Newtonian world, or process and flux, which are Einsteinian, will dramatically affect both how he describes and explains it, and, as it percolates down to gut levels, how he experiences it too. This issue of "linguistic relativity" is a stout and venerable one (see e.g. Whorf [1956], Lloyd [1977]) and it is only possible to not at it here. More easy to tackle are the particular scientific beliefs that permeate the language of a child's home. His lay physics may assert that the bath water always drains away anti-clockwise. Lay chemistry asserts that salt will prevent red wine staining a carpet. Lay zoology may claim that ants don't feel pain, or, as Annie Brandon says in one of Peter Tinniswood's novels, "It's only human for dogs to chase motorcycles". Lay physiology contains a theory about the causes of obesity and the best way to treat a hangover.

At the time they are registered, these beliefs and attitudes often have no

basis in a child's own experience - in his gut science - and may never make contact throughout his life. They may be accepted passively, sight-unseen, from people whom he trusts, in his innocence, to know the truth and explain it to him. And by the time he comes of age, these beliefs have sunk so far down into his world view that he does not even realise they are there. Thus it is, for example, that lay sociology may contain a socially transmitted disease called prejudice, a disorder that is resistant to all known forms of medication.

Those aspects of lay science that are not verbal are very largely visual: they derive from pictures in books and magazines, and images on the TV. Occasionally these images are accompanied by non-verbal sound, such as the cry of an animal, or the electronic bleeping of a robot, but vision predominates, and touch, tase, smell and most importantly the ability to interact and experiment are missing. For a modern child this world is a vast mish-mash of Tarzan, James Bond and Miss Piggy; of space ships, nuclear weapons, pangalactic gargleblasters, tree-frogs and winter sports. It gives him an awful lot to talk and argue about (play grounds reverberate to the greeting "Did you see... last night?") but precious little to do. By the time he comes to school, the average child will possess an immense and undigested store of such knowledge, fantasy and belief in which these three categories are completely inntertwined. He may converse about Life on Earth and Blake's Seven in exactly the same terms. They are equally real in terms of the vivid visual images they employ, and equally unreal in having no connection with the experience of a fourteen year old in Battersea. Such knowledge is absorbed not through physical involvement but through reception and retention. He takes what he is given, and his only choice, if he has one at all, is to switch off. Some lay science may be evaluated with respect to its utility, but mostly its function is to be entertaining and/or to allow one to converse successfully with family and friends. Much, but not all, lay science will therefore be available to consciousness, and capable of articulation, but it is, like gut science, piece-meal and incoherent. What children can and do spend a lot of time doing is improving the coherence and the acceptability of their lay science through discussion and argument with each other (Ryder, 1982).

7. SCHOOL SCIENCE

School science applies initally to a fantasy world - a make-believe universe in which lines can have no width, pulleys no friction, ropes no weight, substances no impurity; where vacuums can be so perfect that feathers drop like lead, where energy is never used up, and where mythical characters like "an electron" and "the square root of minus one", stranger by far than unicorns and talking pigs, abound. On first acquaintance this world seems weird and hypothetical: only after much instruction in accepted theory does one come to call it "ideal". And only in special rooms are the conditions of this arcane cosmos approximated - rooms that a child will learn to call "laboratories". Here he will be given a small amount of magical experience and a large amount of talk, and he will be told that this fairyland of moles and pipettes, rheostats and ribosomes is somehow more "real", more "true", than the everyday world of custard and Granny and bath-times. He will learn that in this "real" world his own experience is untrustworthy, and that there is a "reasonable" distinction between what did happen and what should have happened. He will learn not to be surprised when a course on Human Reproduction turns out to be about rabbits. It is indeed an Alice-in-Wonderland experience.

Symbolic science, as it is transmitted in school, permits a variable amount of active and/or self-directed experimentation, and builds on top of that a linguistic and mathematical superstructure that is sometimes counter-intuitive but never ultimately open to question. $S = ut + \frac{1}{2}ft^2$, and that's it. The learner has little choice, once the decision to take a subject has been made, about whether

TABLE 1

	SITUATION	PREDICTION	ACTION	DESCRIPTION	EXPLANATION	LANGUAGE	LEARNING
GUT SCIENCE	Domestic	about the tangible world	perceptions - motor habits	"experience"	"because I know it"	everyday	trial and error
LAY SCIENCE	domestic, media, science fiction	about real and fantasy worlds	attitudes, play	"beliefs"	"because they say so"	everyday sci-fi	receptive argument
SCHOOL SCIENCE	laboratory	about outcomes of "experiments"	scientific thinking and skills	"facts"	"because it follows"	technical symbolic	receptive illustrations

when, and how much to study, and even less about what to make of it. He accepts knowledge (recent, more experimental curricula notwithstanding) because he is told it is right, or true. This knowledge is articulated, consciously and deliberately transmitted and received, and coherent. It has, or forms, a "body". Note that formal science as it is taught and acquired in school is quite a different thing from the science of the researcher. His activity can be characterised most simply as a rational, conscious, intentional, public and symbolic analogue of the skills of hypothesis generation and testing that are owned tacitly by the young gut scientist.

8. THE INTERACTION OF GUT AND LAY SCIENCE

The problem to be faced when we begin to look at the acquisition of school science concerns its relationships - both functional and in terms of content - with the pre-existing sciences, gut and lay, of the learner. But before we tackle this problem, we need to look in more detail at the relationship between gut and lay science themselves (this section), and at the nature of theoretical conflict (section 9).

Gut science, as we have seen, is primarily experiential. It arises before a child possess language, and it remains preoccupied with the prediction and control of spontaneous action. However, as the child begins to be able to represent his experience in language, so parts of this theory, previously tacit and inarticulate, become attached to descriptions and explanations. These are not taught formulae, but are the child's attempt to communicate his own experiential understanding to others and to himself. Having learnt "milk" and "wet" independently, he can put them together himself to communicate a discovery. This state of affairs is represented in the left-hand part of figure 4. The lower plane contains the majority of gut science that is concerned with action and intuition. The smaller plane, above the left hand end of the lower, represents those descriptions and explanations that have been created by the child himself. Between this verbal/symbolic sub-theory and the experiential domain that underlies it there is an accurate and flexible mapping. Both form part of one integrated mini-theory. They are bits of the same amoeba.

Now consider lay science, which is represented by the two right hand discs in figure 4. Unlike gut science, lay science has its origins in the language that the child speaks, and in the socially transmitted and frequently inaccurate scientific descriptions and explanations that his elders and betters implicitly require him to take on trust. Eating a lot of potatoes makes you fat, unless the people under discussion are Irish, in which case the consequence may not be obesity but stupidity. People feel tired "becuase they have run out of energy". The function of sleep is to "recharge the batteries". Dad's migraines are caused by eating chocolate. Pre-mentrual tension is something that one "suffers from", so that one can no more be held responsible for one's irritability than one can for one's acne or a raised temperature. Now some sub-set of these accounts are known to correspond to one's own experience: they have been "checked out" and found to be accurate. Thus there is an experiential domain (the smaller, lower disc on the right hand side of figure 4) that maps onto some of the descriptions and explanations that a child has bought. And it is very likely that this domain is included to a considerable extent within the domain of gut science. However - and this is the nub of the matter - many of the accounts of lay science refer to the same phenomena as the experiential mini-theory of gut science, <u>but the two levels are unconnected and uncorrelated</u> (see the central overlap in figure 4). In this case a description that one has acquired is held to be accurate, even though it is not underpinned by experiential understanding. Indeed an action that is produced by gut science, and an explanation or rationale for the action that derives from the overlapping but unconnected lay science may even be in conflict. Evans (1980), for example, has shown this

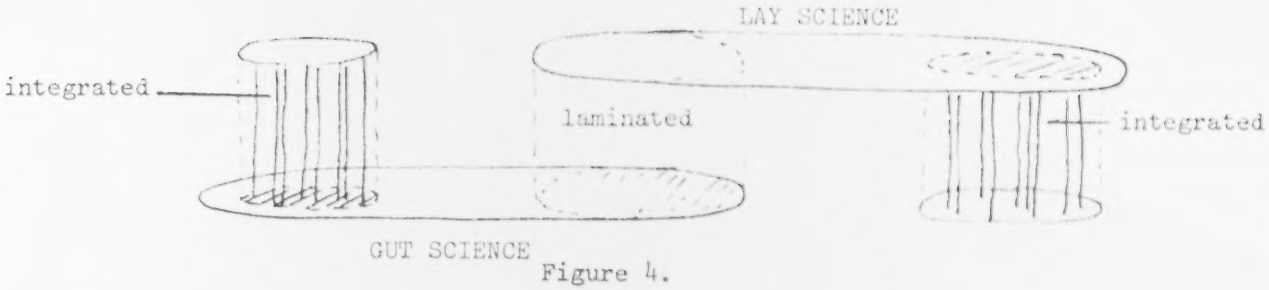


Figure 4.

to be so in certain problem-solving situations, where it is clear that a proposed solution and its rationale are generated by quite separate mini-theories. Thus it is that in many domains of experience, not just scientific ones, a very important part of a child's developmental enquiry is the discovery and putting-to-the-test of latent disparities between his experiential and his socially derived symbolic knowledge. When two mini-theories overlap without being connected, we might refer to them as laminated. When all possible disparities and inconsistencies have been ironed out, and the two theories fully reconciled, they become what we have called integrated.

9. OVERLAP, CONFLICT AND RESISTANCE

We need now to look a little more closely at the psychology of dealing with potential conflicts between mini-theories. The ideal response is, as we have seen, to investigate and resolve it - by integrating the two theories, by subsuming one within the other (engulfment) or by separating out the overlapping area into a new, general purpose mini-theory (abstraction). A fourth alternative is that investigation will reveal that either or both of the conflicting theories is misplaced, and that when appropriately relocated, the overlap is removed. Figure 5 shows these four possibilities. In all of them the conflict is removed

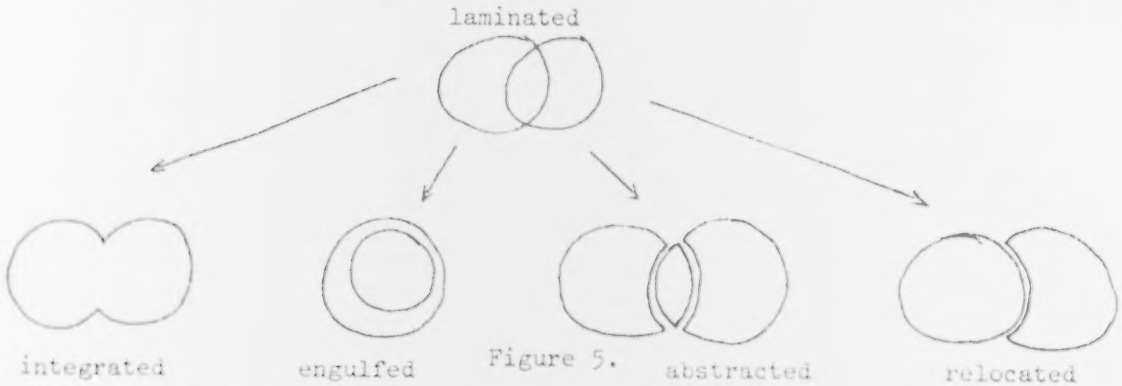


Figure 5.

as a result of further experimentation and data collection. The outcome is an improvement. It is quite possible, however, for a child to deal with the conflict by being a bad scientist rather than a good one. Bad scientists don't like giving up their theories, and they find ways of removing or denying their inadequacy through a variety of defensive ploys.

Before we look at some of these ploys, it is worth asking why people opt for a no-learning solution to conflict, rather than a real resolution. There are two reasons: either they feel no need to investigate, or they feel a need not to investigate. In the former case the bother of testing out and resolving discrepant predictions doesn't seem worth it. "What's the point?" - a question beloved of school pupils - is a good question to ask. Most of the calculations

required of a student of kinetics or dynamics presuppose a frictionless world - and where do we meet such a world in everyday life? It is a rare teacher who would even think of taking his class roller-skating or ice-skating in order to get a (gut) feel for such a world. And even if the connection is made, will all this theory actually help me skate better? Not at all. Thus although in some sense there is a potential conflict between gut science and school science in this domain, it is not actually worth bothering about. I may be told that Newton's Laws are "righter" than my own gut theories - but I know that my gut theories work better.

The second reason for being a bad scientist is if giving up an existing theory is too threatening. I have a personal stake in believing that things are a certain way, that is, if I am identified with a point of view, then I cannot give it up without also giving up something of myself (Claxton, 1981b; Head and Sutton, 1981). If I am identified with my own competence, for example, then even to admit I might be wrong may be too scary. Learning in this case becomes a threat to myself. Alternatively if the theories that are in conflict are very basic to my world view, then to change one might mean a radical upheaval of everything I believe. Relativity theory is notoriously difficult to get a feel for, for just this reason. Learning may therefore be a threat to my knowledge-structure. Finally to give up a cherished gut or lay theory may put me in conflict with my society, my family and friends. Learning becomes a threat to my social stability. For any one of these good reasons we may opt for defence.

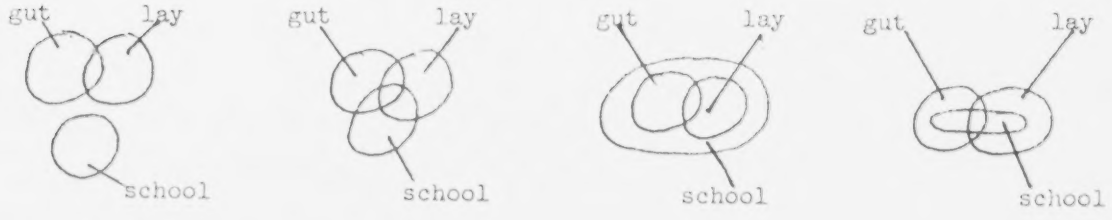
How does defensiveness work? One ploy is to simply ignore the conflict, pretend it isn't there, and leave the two theories laminated. Everyday life is full of examples of lamination. "Don't do as I do, do as I say", forms of hypocrisy, moral dilemmas, guilt - all are created by the concurrent activation of conflicting mini-theories. Often one theory controls action and the other controls thought. Or the two theories may generate conflicting streams of thought, as in the "I want"/"I ought" battles that are familiar to most of us. A second ploy that we can use, often in conjunction with the first, is to arbitrarily relocate one of the theories. We just re-write the Situation specification so that the conflict is removed. This I suspect is what many science pupils intuitively do. Their developing knowledge about various topics in physics, say, is not "called" or "addressed" by the topics themselves, but by the context in which the study is taking place - namely physics lessons. Thus their understanding of force, relative motion or electricity, acquired in school, is only triggered by school, and not by real-life experiences. There the old gut/lay science continues to control prediction, action, description and explanation undisturbed, and consequently unimproved.

The process of relocating theories to suit ourselves, and to save ourselves the bother of having to think or learn, is ubiquitous. It is not uncommon, for example, for people who are obviously prejudiced against West Indians to have West Indian friends. Confronted with the apparent discrepancy we relocate the friend: "He's not black; he's my mate, aren't you Charlie?" Such verbal sleight-of-hand often works, in the sense that it costs little, and gets us out of a corner. The problem is that it leaves the prejudice intact. My experience with Charlie has no effect at all on the strength or viciousness of my prejudice towards other, "real" black people.

When children do the same thing with their school science they are thereby insulating their gut and lay theories from change. And now two further questions present themselves. Is this compatible with the science teachers' aims? And what is the effect of this mental apartheid on the acquisition of school science itself? Is it helped or hindered? These now become the crucial issues for science educators - both theorists and practitioners.

10. TEACHING SCIENCE

The central feature of the present diagnosis is that school science often makes little of no connection with children's intuitive understanding. When it is taught formally, through unfamiliar words and formulae, or through familiar words used in unfamiliar ways, using special techniques and strange bits of apparatus applied to "chemicals" or "specimens", then it clearly creates its own, separate domain of experience, in just the way that Calculus and Latin and Seventeen Century European History do. In this case the relation of school science to gut and lay science is as in figure 6a. Heating is done not with



a b c d

Figure 6.

a stove but a "bunsen burner": containing is done not by jars and bottles but by "conical flasks" and "measuring cylinders". There are no knives and forks, and the only spoons are for deflagrating - whatever that is; no talc, but instead the mysterious "lycopodium powder". And so on. Familiar words, like energy, speed, weight, compound, solution, mass, reaction and fittest (survival of) are given new and tricky meanings. In this case what the child learns will be automatically contextualised to the lab atmosphere and the lab language.

Aware of this, and seeing it as undesirable, lower school curricula, and many teachers, now seek to link school science with a child's out-of-school experience. By using real-life materials and familiar analogies, they hope to make science more "relevant". They assume that by creating an overlap of content, as in figure 6b, the child's real-life competence will be affected. One of the major implications of the present analogies is that this won't do. For gut and lay science to be modified, much more has to happen. Otherwise school science is either subjectively relocated by the students, so that it is not about motion but about physics, or it remains overlapping but unintegrated - merely laminated. For integration to occur, all the following conditions must be successfully fulfilled:

(i) two mini-theories are laminated;

(ii) they must be simultaneously active;

(iii) they must generate conflicting predictions, actions, descriptions or explanations;

(iv) the conflict must be perceived/acknowledged by the learner;

(v) the learner must feel the need or the benefit of resolving the conflict;

(vi) appropriate learning strategies must be engaged;

(vii) defensive strategies must be eschewed;

(viii) a satisfactory resolution of the conflict must be found.

It is therefore not sufficient to demonstrate the effects of air pressure by jamming a plastic dustbin lid onto a bench top, instead of with the esoteric

Magdeburg Hemispheres. Nor to use snooker balls as an analogy for the reflection of light. An adolescent boy may have gut knowledge of snooker from playing down the Club every Tuesday evening. He may have lay knowledge from watching the experts on TV. Yet they may not meet with each other, let alone with the problems of CSE optics. Such contextualisation of knowledge and skill is very common. "Innumerate" school kids are to be found scoring effortlessly at darts or ten-pin bowling. "Hyperactive" kids are to be found fishing. "Disruptive" kids are to be found baby-sitting and taking charge of the washing-up in the Youth Hostel. Many of their reactions, intellectual and social, to events in school are dependent on their being in school. Out of school, after two large gin-and-tonics, the Health Education lessons on contraception and V.D. quite literally belong to another world. If the worlds are to communicate and interact, then more is required than common terms and common topics (Claxton, 1981b).

To put it another way, although one may describe the two theories as generating hypotheses about the "same thing", functionally they may not be simultaneously triggered by this sameness. As we saw earlier, a child may possess general mini-theories that make predictions about "the displacement of liquids", but which of these is activated on any occasion will depend on other, incidental, features of the situation - like whether the liquid container is a cup, a bath or a swimming pool - and not on the feature of "liquid being displaced". He may possess both school knowledge and gut knowledge in the domain called "relative velocity", yet manifest one in the classroom, and the other when playing "bicycle jousting" with his friends, or when he sticks his hand out of a speeding train. More generally, it is quite likely that the situational features called "discussion", "give me a reason why", "what do you think?" and so on will act as triggers for school or lay scientific discourse, while a situation that is construed as requiring action, not words, will, regardless of what kind of action or what kind of event, trigger gut science. Thus the differing perceived demands of situations will be sufficient to recruit either gut science or lay science (but not both) even though the content may fall within the domain of each. The two theories, in others words, may be often co-extensive, but less often co-active.

These considerations force us to raise the question of the aims of science teaching. What are we teaching it for? On the answer to this question depends how we view and deal with overlap and conflict. It now seems to me that there are at least two different aims for science teaching, and that they are incompatible. They demand different curricula, different pedagogies, different relationships between teacher and taught, and different forms of assessment. When these two aims are confounded, students and teachers are confused, and the achievement of both sets of goals is thereby undermined.

Teaching symbolic science. One aim is for children to acquire an accurate understanding of "symbolic" science - that body of knowledge and technique that professional scientists subscribe to and presuppose. Why does one want children to know this formal science? Perhaps because one sees it as worthwhile in its own right: something that every "educated person" should have had a taste of. Perhaps one wants it to be available to pupils who, for whatever reason, find it interesting, as many do. Perhaps one is teaching it because "knowing science" is a passport to university or other opportunity, a passport that needs to be stamped by Examining Boards. Or perhaps what is arguably the best reason: a teacher just enjoys turning young people on to something that fascinates and intrigues him. All of these legitimate reasons require a teacher to teach his pupils what other people know, and to teach them a prescribed set of methods for finding out, recording and interpreting this knowledge. He cannot get away from the fact that he is trading in "rightness". Right definitions, right facts, right results, right techniques, right observations, right understandings. Thus they must view children's own knowledge - their gut and lay sciences - as not just different, but very often wrong. The criteria by which pupils' performance is judged are external: they are concerned with historical, logical and technical accuracy. The pupils' job is to retain and comprehend what they are told, or what

they are channelled towards finding out. Experimental work is designed to illustrate: not all results are equally valid. By tolerating childrens' "misconceptions" or "inaccuracies" too long, one does them a dis-service. Eventually they must be put "right".

I am not saying, nor do I believe, that such goals and such teaching styles are questionable or misguided in any sense at all. It is not my intention to say anything about what science teaching should be about. What I am saying is that if one adopts certain goals, then definite consequences follow about how these goals can be achieved. If one wants to teach formal science, then one cannot but see childrens' alternative conceptions as misconceptions. Particularly if one is teaching science to children because one feels it to be a worthwhile body of knowledge in its own right, that they ought, at least in part, to be exposed to and remember, then overlaps between school science and gut and lay science will be viewed in a certain way. Specifically one needs to know when, or whether, these overlaps will facilitate or impede the learning of symbolic science. If I use everyday examples or analogies, will this help the principle that I am trying to get across to stick or will it only confuse them? Such a teacher's concern is not with increasing the accuracy, articulateness, coherence or effectiveness of the child's everyday encounters with nature, but with the effective transmission of Science with a capital S. I am free to vary my teaching style between real life and the abstract, and between chalk-and-talk and experimental work, subject only to the aim of optimising the retention and comprehension of concepts, formulae, facts and skills. And in examining my pupils' knowledge, my primary aim must be to see how right it is - a job for which formal examinations are reasonably well suited.

Furthermore it is reasonable for such a teacher to see formal science not just as a better theory, but as a meta-theory, which provides its owner with a coherent overview of a variety of natural phenomena that he had previously learnt to deal with piecemeal. Formal physics, for example, provides one with an awareness of a small set of features (mass, density, velocity, etc.) and their relationships that turn out to have a broad range of extremely accurate predictive power. That is to say, the domain of school science should be seen by its students as subsuming the domains of both gut science and lay science (as in figures 6c and 6d). This aim is an enlightened one, for not only does it make science "relevant", but in theory it makes it relevant and accessible to children of all academic abilities and social backgrounds. But we can now see that although this goal is enlightened, it is misguided, for the teaching that brings about these useful shifts in everyday competence is not the teaching that gets 'O' levels.

We need to know more about the role of metaphors and analogies in science teaching, for example (Sutton, 1978,1981). While there are occasions on which familiar images help students to grasp new ideas, there are other circumstances in which they seem to hinder. If one takes the metaphor too literally, or it is too compelling, then it loses its "as if" quality, and all its features, both relevant and incidental are transposed to the new concept. It is the experience of some science teachers that their pupils' gut and lay theories provide not a foundation on which school science can be built, but a sink, down which it all too rapidly drains away. Everyday meanings of words, for instance, constantly seem to choke the new, technical meanings that the teacher is trying so hard to implant. However many times we teach it, by the next lesson it's gone again. "We did that in the second year Miss", they say - but what they did seems to have left no trace at all. Now the teacher of formal science is free to ignore or separate real-world knowledge when it gets in his way. In fact it may well be (though I know no proof of this) that the most successful science students are those that manage to keep the domains most separate, and thus avoiding the smothering of new ideas by old.

Amplifying Competence. However there is often a disparity (of just the kind we have been discussing) between this modus operandi and a teacher's declared intention in teaching science, which is the more ambitious one of actually enhancing their pupils' everyday competence with physical, chemical and biological material. If such a teacher is to take his own aims seriously, then it is not sufficient for his pupils to treat science as just another subject, to be acquired and comprehended as accurately as possible. Now the overlaps are not ancilliary; they are crucial. And his job becomes that of deliberately contriving disparities, persuading children to entertain these disparities as felt conflicts, and supporting them through the process of conflict-resolution so that they do not opt for a premature or a defensive solution, but persist until a satisfactory reconciliation and integration of the two, originally disparate, theories is found and consolidated. Like the exemplary teacher of Nuffield Science, he will spend more time asking pupils what they think than telling them what he thinks, and will have to be prepared to let them design and run their own tests, even if flawed, with great self-restraint. Thus the generation and resolution of conflict requires a rather open-ended and student-centred teaching style - because each child has to work with his own individual gut science and lay science. It is all too easy for these theoretical collisions to seem like just another academic exercise, in which the students have no real involvement, unless they are elicited by a teacher who has a good sense of the real circumstances and preoccupations of his students. Thus uncovering, listening to and working with children's scientific intuitions (Sutton, 1980) emerges not as a Good Thing, based on some child-centred ideology, but as the only effective way of achieving certain educational objectives that one is free to adopt or not. If the present analysis is correct, such a pedagogy is simply Good Psychology.

What emerges, therefore, is that the teacher who intends to change his pupils' scientific intuitions and beliefs has set himself a complex and difficult task. For on the one hand he will have a considerable struggle to generate the conflicts that are necessary precursors to expanded intuition, and on the other, when he does succeed, he may find he has opened up a can of emotional worms that prevent the child "seeing it through" and which may divide not just his scientific, but his personal loyalties. Such a teacher, unlike the one whose goal is to transmit symbolic science, must be interested in the children's alternative conceptions of reality and must help them to be interested in their own intuitions as well. He cannot afford to label these intuitions "wrong" and to "teach" something better, for he knows that will rarely do the trick. Both the questions and the answers must be not just received by the children: they must be appropriated by them. The teacher can suggest, but he cannot achieve his goal by telling. And if he suggests too much or too fast, he will lose the vital ingredient of the learning committment, without which integration will not be pursued. It is not "bad" to tell children things: it is just that tuition does not happen to produce the kind of learning that this sort of teacher is after.

We have here an important example of a crucial educational naivety, which is that all types of learning experience produce the same type of learning outcome; and that while learning may vary in amount, it does not vary significantly in quality. Thus arguments about teaching style are reduced to matters either of efficiency or of ideology. Does it work, or is it right? What needs saying loud and often is that questions of efficiency are contingent on questions of ideology. Different aims of teaching require different kinds of learning, and different kinds of learning require different kinds of teaching. Acquiring knowledge is a different activity from developing one's competence, and learners pursuing one or the other require very different kinds of assistance.

Teachers persuaded of the reality and the relevance of their pupils' pre-existing scientific knowledge are apt to respond by saying "O.K. Now how do I find out what these intuitions are, so that I can take them into account?" And techniques such as those reviewed by Sutton (1980) do exist. Or they ask "What

are these intuitions? What common alternative conceptions or misconceptions am I likely to come across in my pupils?" And much data is being gathered (e.g. Archenhold et al, 1980) that begins to answer this question, too. However it is important to notice that this kind of response usually presupposes the teaching-symbolic-science goal of science education. Teachers keep control, and keep the responsibility for seeing that the students knowledge develops in the "right" direction. They assume that such intelligence about the enemy positions will enable the intellectual battle to be more easily won by the forces of symbolic science. It is not clear that this is so, however, Despite much talk and some research about the importance of establishing students' "cognitive structure" or "Piagetian stage" or "entering behaviour" so that teaching can be aimed appropriately, little or no practical benefit to teachers has accrued. And the whole philosophy of trying to decide what other people are ready and/or able to learn has always seemed to me faintly absurd. Only if I have lost all faith in the natural wisdom of appetite do I have to decide when you shall have your next meal, and what it shall be.

Finally, we might note a few further repercussions. Some teachers are motivated to teach symbolic science by a desire to systematise childrens' thinking. To them the contradictions, discrepancies and situational-specificities of children's gut and lay sciences are an anathema. They call a child's reasoning perjoratively "ad hoc" and their main wish is to tidy it up, because order and consistency are intrinsically valuable. Yet this elegance, as we have seen, can only be bought at a considerable cost in time and tolerance - a cost that the learner may see no point in paying if, to him, his mini-theories work welll enough. In some domains, such as inter-personal relationships, lack of integration leads almost inevitably to a lack of integrity, and the ensuing hypocrisy, though ubiquitous, is deplorable. But in the domain of the physical sciences the case is more open, it seems to me.

Other teachers' concern is not so much with the change of scientific knowledge as with helping their students to "become scientists". If this means gut scientists - people who are proficient at the everyday, intuitive business of data collection and theory development - then we have to admit that their clients are already highly trained and highly skilled. They have been at it non-stop since the day they were born, and their success is witnessed by the fact that they are still alive. It is not clear what the science teacher could or should do to intervene. Making the whole process more intellectual, for example, as often seems to impede the development of practical ability as it does enhance it.

The alternative process aim of school science is to create good research scientists - people who can reason logically, guess creatively and experiment precisely within the symbolic arena. The ethical problem here is: how is this relevant to the majority of pupils? The psychological problem is that it requires a lot of freedom to develop good research skills - more than most schools could tolerate. For as well as logic, knowledge and precision the researcher needs patience, receptivity, wonder and ingenuity, and none of these is easily trained or examined.

Another issue concerns the "fair test" of what students have learnt. Examiners often think they are setting a clever exam when they find a kind of problem to which taught expertise is potentially applicable that has not itself been previously encountered by the examinees. The ability to see the relevance of what one knows to the new problem, and to apply it correctly, is taken to be an index of "depth of understanding", or even of "intelligence". Yet if all knowledge is contextualised with respect to the contexts, contents and purposes for which and through which it was acquired, then this rationale becomes suspect. In what sense can an unfamiliar combination of context, content and task be a fair test of learning when we have no right to suppose that accurate and confident transfer can ever take place? Performance on such tests is likely to be determined more by a person's willingness to gamble with their knowledge than by the quality of that knowledge.

If we cannot know "what", without also having a sense of "what for", then the onus is on teachers to teach science for a purpose. If that purpose is passing exams, let us be clear about that, and do all that we can to ensure that our students' knowledge responds to the appropriate call. We can drop the faintly guilty feeling that such "coaching" is somehow unfair, cynical or too materialistic. Equally, if our purpose in teaching is to improve on-the-spot, heat-of-the-moment, real-world prediction and action, then let us be equally clear that an entirely different set of detonators needs to be built in at the time of learning. We cannot have it both ways.

The science teacher has a choice. He can present his subject as a new, virgin land to be explored and colonized - with the aid not of compass and plough, but of compasses and petrie dish and Maxwell's corkscrew rule. Being the only settlers there, Scientists have no need for arms or defenses. But if the teacher sees his formal science as trying to civilise a land that is already densely populated with residents who have their own, perhaps "primitive" but certainly workable culture, then his missionary zeal may well be met with studied indifference or even active resistance. If he designs his teaching so that school science is constantly treading on the toes of previously held beliefs, he should not be too surprised if the latter say "Ouch!" and do their best to ignore or remove the intruders. For his advice and theories to be accepted, they need to be offered with considerable tact, understanding and respect. (The problem is exactly analogous to that of offering technological aid to the Third World.) To return to the image with which we started, it would be a poor husbandman who blamed the failure of his crop on the lack of "ability" or "motivation" of his fields, and left it at that. His job does not begin and end with the act of broadcasting the seed: he must know both seed and earth before and after they are introduced to each other. It may feel more comfortable to find something to blame, but blaming is not a horticultural activity, and it will not affect the harvest.

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